

Multiwavelength Pyrometry to Correct for Reflected Radiation

Daniel L.P. Ng
Lewis Research Center
Cleveland, Ohio

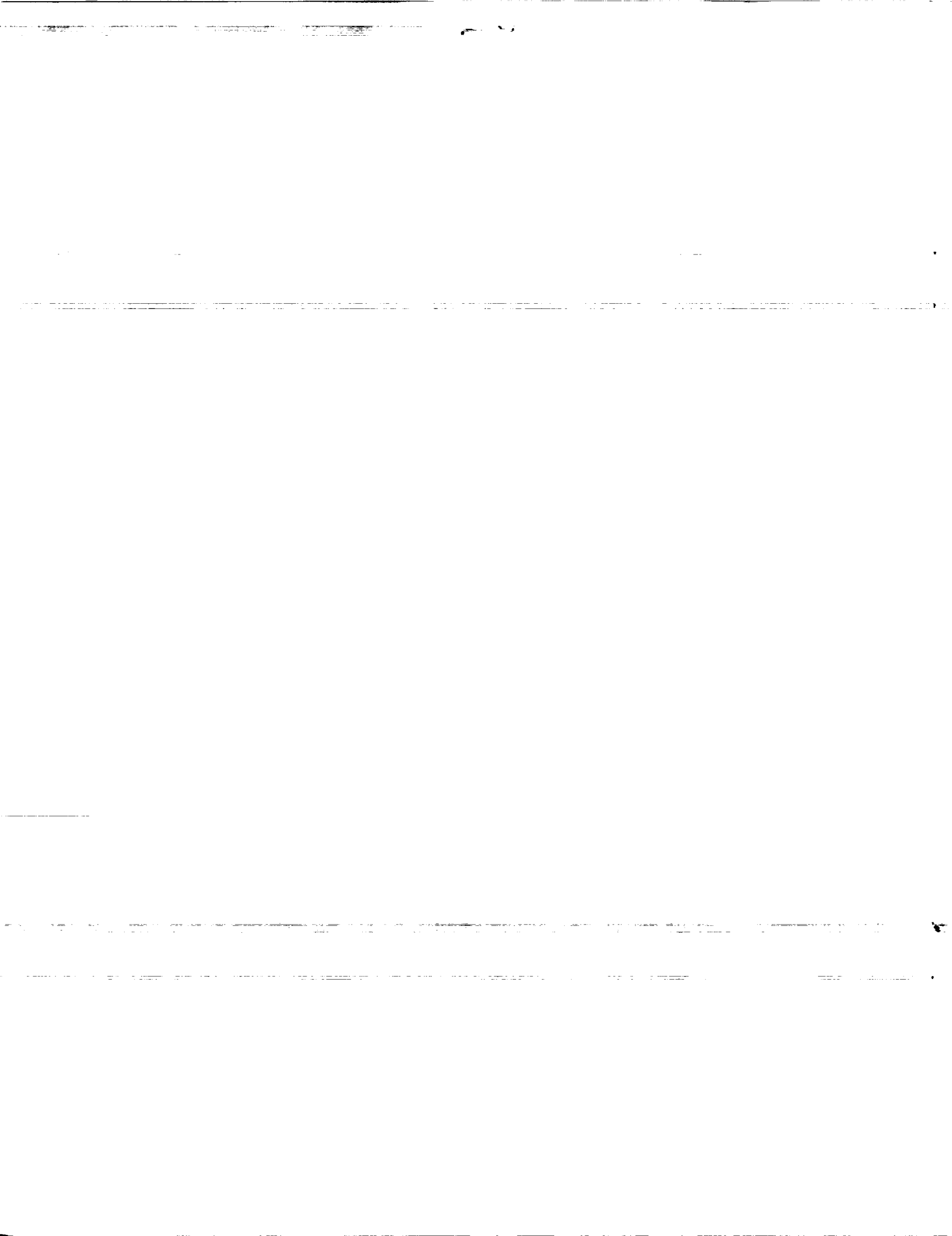
June 1990

(NASA-TM-102578) MULTIWAVELENGTH PYROMETRY
TO CORRECT FOR REFLECTED RADIATION (NASA)
13 p CSCL 14a

N90-23714

Unclas
G3/35 0289144

NASA



MULTIWAVELENGTH PYROMETRY TO CORRECT FOR REFLECTED RADIATION

Daniel L.P. Ng
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

SUMMARY

Computer curve fitting is used in multiwavelength pyrometry to measure the temperature of a surface in the presence of reflected radiation by decomposing its radiation spectrum. Computer-simulated spectra (at a surface temperature of 1000 K; in the wavelength region 0.3 to 20 μm ; with a reflected radiation-source temperature of 700 to 2500 K and reflector emissivity from 0.1 to 0.9) were generated and decomposed. This method of pyrometry determined the surface temperatures under these conditions to within 5 percent. The practicability of the method was further demonstrated by the successful analysis of a related problem - decomposition of the real spectrum of an infrared source containing two emitters to determine their temperatures.

INTRODUCTION

In pyrometry, the temperature of a surface is determined by measuring the emitted radiation. The emitted radiation obeys Planck's blackbody distribution law. In conventional pyrometers (the so-called single-color pyrometers), the radiation is measured in a narrow wavelength band, usually in the visible or near-infrared bands (in the region of 0.5 to 1.0 μm). This method of temperature measurement requires some knowledge of the surface emissivity. Two-color pyrometers measure the emitted radiation in two wavelength bands, and by assuming that the ratio of emissivities in the two bands is known, the surface temperature is determined without knowing its emissivity. In general, as long as the emissivity does not change rapidly with wavelength, accurate temperature measurements are obtained. However, both methods are susceptible to errors caused by reflected radiation. Reflected radiation originates from sources other than the surface under consideration and reaches the detector through reflection from the surface. Ceramics are materials from which future advanced propulsion systems will be built. This class of material typically has low emissivity (0.15 to 0.8); hence, there is high reflectivity in the wavelength band where conventional pyrometers operate (ref. 1). Consequently, a potential for large error exists when pyrometry is employed to measure the temperature of ceramics. To correct for the reflected radiation, we propose the use of multiwavelength pyrometry that measures temperature by curve fitting the measured radiation spectrum. This method has been used to simultaneously measure temperature and spectral emissivity with accuracy up to 1 percent (refs. 2 to 4) and to measure temperature distribution with a known spectral emissivity (ref. 5).

REFLECTED RADIATION

Figure 1 shows a pyrometry arrangement in which both the emitted and reflected radiations reach the detector. One can see that, in addition to the

radiation (signal) originating from the measured surface at temperature T_e , there is an undesirable component originating from an extraneous source at temperature T_r . The arrangement shows that the radiant flux detected by a pyrometer can be represented mathematically as

$$\phi_\lambda = \phi_{\lambda,e} + \phi_{\lambda,r} \quad (1)$$

where ϕ_λ is the detected flux decomposed into two components: $\phi_{\lambda,e}$, caused by emission from the surface under consideration and $\phi_{\lambda,r}$, caused by reflection from the extraneous source. As a result, depending on the magnitude of this flux, the final temperature measurement contains unavoidable errors. Neither the one-color nor the two-color pyrometry is capable of accounting for and, hence, eliminating this source of error.

By application of Kirchhoff's law, and the Planck distribution of blackbody radiation $L_\lambda(T)$, the two components are expressed as

$$\phi_{\lambda,e} = ae_e(\lambda)L_\lambda(T_e) \quad (2)$$

$$\phi_{\lambda,r} = ab\sigma_e(\lambda)e_r(\lambda)L_\lambda(T_r) \quad (3)$$

where

$$L_\lambda(T) = \frac{c_1}{\lambda^5} \frac{1}{\exp(c_2/\lambda T) - 1}$$

In equations (2) and (3), the quantity a is a geometric constant of the pyrometer, and b is a geometric constant of the experimental setup containing quantities such as the view factors (solid angle). The radiation constants c_1 and c_2 are given by

$$c_1 = 2c^2h \quad (4)$$

$$c_2 = ch/k \quad (5)$$

where $c = 3 \times 10^8$ m/sec is the velocity of light, $h = 6.6 \times 10^{-34}$ J-sec is the Planck constant, $k = 1.38 \times 10^{-23}$ J/K is the Boltzmann constant, and $e_e(\lambda)$, is the emissivity of the surface, which is generally a function of wavelength and may also be temperature dependent. The quantity $e_r(\lambda)$ is the emissivity of the extraneous source, and for a blackbody, $e_r(\lambda) = 1$. The quantity $\sigma_e(\lambda)$ is the reflectance of the target surface and is equal to $(1 - e_e(\lambda))$, if it has no specular component. Multiple reflection between the two surfaces is neglected. Curves of the Planck radiation distribution for a blackbody are shown in figure 2 as a function of wavelength for different temperatures. A temperature T can be calculated from the relative spectral distribution near the peak because the wavelength at the peak varies inversely with T (Wien's displacement law). It is thus possible to find the two temperatures T_e and T_r in figure 1 because of their different spectral distributions.

PYROMETRY METHODS

One- and Two-Color Pyrometry and Polaradiometry

Temperature measurement by pyrometry is based on detecting and analyzing the radiation of equation (1). In both one- and two-color pyrometry, the

reflected radiation is ignored or considered small compared to the emitted radiation. This is not a bad approximation for two-color pyrometry, if the extraneous radiation sources have temperatures not much different from the target surface.

In the single-color pyrometer, the radiation emitted in a narrow wavelength band $\Delta\lambda$ centered at λ_1 is detected by a suitable detector system. The detected flux ϕ is equal to the integral obtained by integrating equation (2) over this wavelength region:

$$\phi(\lambda_1) = a \int_{\lambda_1 - \Delta\lambda/2}^{\lambda_1 + \Delta\lambda/2} e_e(\lambda) L_\lambda(T_e) d\lambda \quad (6)$$

When $\Delta\lambda$ is small, it can be assumed that the integrand in equation (6) is constant and that the integral is approximated by $\Delta\lambda$. Then the detector signal is

$$s_1 = k_1 a \Delta\lambda e_e(\lambda_1) \frac{c_1}{\lambda_1^5} \frac{1}{\exp(c_2/\lambda_1 T_e) - 1} \quad (7)$$

where k_1 is the detector sensitivity factor. By knowing the emissivity of the body, we can determine its temperature from the detector signal.

If a second narrow wavelength band $\Delta\lambda$ centered around λ_2 is selected, the detected signal s_2 is

$$s_2 = k_2 a \Delta\lambda e_e(\lambda_2) \frac{c_1}{\lambda_2^5} \frac{1}{\exp(c_2/\lambda_2 T_e) - 1} \quad (8)$$

The ratio of equations (7) and (8) contains the ratio of the emissivities, which is unity if they are the same. This is the two-color pyrometry method. Neither method addresses the issue of reflected radiation. If it is not negligible, the resulting error can be substantial.

Murray (ref. 6) demonstrated an ingenious method for obtaining the temperature of a surface by explicitly employing the reflected radiation from a known external source. By carefully analyzing the emitted and reflected radiations, explicitly taking into consideration their polarizations (polarization parallel and perpendicular to the incident plane), and applying Kirchoff's law in a narrow band around λ , Murray obtained an expression for the signal I caused by the combined radiation.

$$I = 1/4 \left[E_{BR}^2 + (e_p + e_s)(E_{BS}^2 - E_{BR}^2) + (e_p - e_s)(E_{BS}^2 - E_{BR}^2) \cos^2\theta \right] \quad (9)$$

In his expression, e_p and e_s are the sample emittances for radiation polarized parallel and perpendicular to the plane of incidence; E_B^2 is the

square of the amplitude of the radiation of wavelength λ from the blackbody with temperature T ; the subscripts R and S refer to the reflecting surface and the reference source; and θ is the polarizer analyzing angle.

This polaradiometer signal contained a constant dc component and a sinusoidal ac component proportional to the difference between emissivities and the difference between the emitted and reflected radiations. By substituting

$$e_e(\lambda) = (e_p + e_s) \quad (10)$$

$$(1/4)E_{BS}^2 = \frac{c_1}{\lambda^5} \frac{1}{\exp(c_2/\lambda T_r) - 1} \quad (11)$$

$$(1/4)E_{BR}^2 = \frac{c_1}{\lambda^5} \frac{1}{\exp(c_2/\lambda T_e) - 1} \quad (12)$$

into the dc component, the quantities in the dc component are identical to the results represented by equations (1) to (3).

Pyrometry by Curve Fitting

Unlike Murray's polar-pyrometry which depended on knowledge of the external blackbody temperature to measure the temperature of the surface, the proposed pyrometry technique will be able to correct for the interfering effect of reflected radiation and to measure the temperatures of the surface and the extraneous source simultaneously. In polar-pyrometry, as in the one-color pyrometry, radiation is detected in only one, narrow, wavelength band. The proposed technique calls for measuring the intensity of the radiation in the wavelength region on both sides of the peak in the blackbody curve not - just at a narrow band, but at many wavelengths.

A spectral radiometer is well suited to obtaining a spectrum represented by equation (1). It is a spectrometer which accurately measures the radiation emitted by a body as a function of wavelength. It has high spectral-resolution capability, with spectral steps as fine as 5 Å. Once a spectrum is obtained, statistical techniques in spectroscopy and other fields of research can be used to extract the parameters such as a , b , T_e , and T_r by fitting the mathematical expression of equation (1) (with eqs. (2) and (3) substituted into it) to the experimental radiation spectrum. In curve fitting, an initial set of approximate values for the unknown parameters is assumed. From these initial values, the expression given by equation (1) is evaluated. The residuals, which are the differences between the calculated and the experimentally observed quantities, are obtained. Next, the values of the unknown parameters are varied according to some mathematical algorithm, and a new set of residuals obtained. This is performed for many iterations so that the sum of the squares of the residuals gets progressively smaller, and the set of parameter values which produces the least squares will be the best estimate. In this way, the experimentally obtained spectrum has, in fact, been decomposed into its emitting and reflecting terms (i.e., the temperatures are simultaneously determined).

COMPUTER EXPERIMENTATION

Simulated composite spectra were generated mathematically according to equations (1) to (3). These spectra consisted of radiation from a surface with emissivity $e_e(\lambda) = \text{constant}$ and temperature T_e , and reflected radiation from a blackbody with emissivity $e_r(\lambda) = 1$ and temperature T_r . The chosen temperature T_e was 1000 K and T_r values were 700, 1500, 2000, and 2500 K. Only three significant figures were retained by this calculation. This numerical roundoff is equivalent to the introduction of some error into the data. The wavelength region of the simulated spectrum is from 0.3 to 20 μm represented by 37 equally spaced channels. Values of e_e vary from 0.1 to 0.9.

The temperatures of the two surfaces and the emissivity e_e were determined from the spectra. These were decomposed on a personal computer by running a commercial, scientific, statistics package (with least-squares, curve-fitting capabilities) called RSI. Other similar computer software could also have been used.

Curve fitting decomposes a spectrum into its constituent Planck functions by simultaneous extraction of the two temperatures. The computer program also yields the standard errors of these quantities resulting from the statistics of fitting the data to the functional relationship assumed by equations (1) to (3). The reported significance level is 0.0001. In the present computer experimentation, we define the error as the deviation of the fitted temperature from 1000 K. These errors are of the same order-of-magnitude as those estimated statistically by the computer program. The variation of these errors with temperature and emissivity is shown in figure 3. It shows that as the emissivity decreases, the fractional error of the result increases rapidly. The results indicate that for emissivity larger than 0.3, there is sufficient accuracy in the temperature so determined.

By increasing the number of channels in the wavelength region represented by the spectrum, the fractional error can be reduced. The case of $T_e = 1000$ K, $T_r = 1500$ K, $e_e = 0.1$, and bandwidth 0.3 to 20 μm is shown in figure 4. When the number of channels is increased from 37 to 193, 394, 462 and 924 (corresponding to channel spacing of 0.5, 0.2, 0.1, 0.05, and 0.02 μm), the fractional error decreases from 0.05 to less than 0.01. However, this increase in accuracy is accompanied by a corresponding increase in computation time.

The fractional error increases when the spectral bandwidth describing the spectrum is reduced. In addition to the 0.3- to 20- μm wavelength region, the following wavelength regions were also investigated (fig. 2): (1) 1.8 to 6 μm (corresponding to detecting radiation greater than 30 percent of the 1000 K peak), (2) 1.2 to 10 μm (corresponding to detecting radiation greater than 10 percent of the 1000 K radiation peak), and (3) 1.0 to 15 μm (corresponding to detecting radiation greater than 2 percent of the 1000 K peak). The results in figure 4 show that the bandwidth should be at least 1.2 to 10 μm (a wavelength ratio of 8).

A channel spacing of 0.05 μm seems to be an optimal value. The fractional error for various extraneous source temperatures, as a function of emissivity with this channel spacing, is shown in figure 5. It can be seen that except for an extraneous source temperature of 2500 K and surface emissivity 0.1, the fractional error for all the other situations is less than 0.04. The results

indicate that for this optimized channel spacing of $0.05\text{ }\mu\text{m}$, there is sufficient accuracy in the temperature determined when the emissivity is larger than 0.2, compared to the necessary value of emissivity larger than 0.3 mentioned previously when the channel spacing was $0.5\text{ }\mu\text{m}$.

It is informative to compare the flux ϕ_e from the surface to the flux ϕ_r from the reflected extraneous source. Integration of equations (2) and (3) over the range of 0.3 to $20\text{ }\mu\text{m}$ is approximated by integration from zero to infinity. The resultant flux follows the T^4 Stefan-Boltzmann law. The flux ratio ϕ_e/ϕ_r is given by

$$\frac{e_e(\lambda)}{b\sigma_e e_r(\lambda)} \left(\frac{T_e}{T_r} \right)^4 \quad (13)$$

For the case $e_e(\lambda) = 0.1$, $e_r = 1$, $\sigma_e = 1 - e_e(\lambda)$, $T_e = 1000\text{ K}$, $T_r = 1500\text{ K}$, and $b = 1$ (b is given by the ratio of the solid angle subtended by the 1500 K body and 2π), this flux ratio is 0.022. Thus the temperature can be determined in the presence of high levels of reflecting flux.

INSTRUMENTATION

A spectral radiometer is used to obtain a complete spectrum of the body whose temperature we want to measure. Several commercial units exist that operate from about $0.3\text{ }\mu\text{m}$ to as far as $20\text{ }\mu\text{m}$. These instruments are completely automated by microprocessor control. The resultant spectrum is in digitized numerical form and can be easily transferred to a computer system such as the IBM, IBM PC, and the VAX for processing and analysis.

It may take about 30 sec to accumulate a spectrum, but for development purposes, this is quite adequate. The collected spectrum is then analyzed by a statistical program. However, in many applications, the 30-sec data-acquisition time may be too slow. In that situation, an optical multichannel analyzer, which accumulates the whole spectrum instantly, can be used.

Presently, most optical multichannel analyzers use array silicon detectors, which are sensitive from about 0.2 to $1\text{ }\mu\text{m}$. The spectra of transient events are routinely collected by workers in spectroscopy. For pyrometry purposes, in order to detect the whole spectrum, operation up to at least $2.5\text{ }\mu\text{m}$ is required. Fortunately, newer detectors, such as InGaAs and PtSi, are becoming available in array packages. Thus, the data acquisition can be instantly accomplished.

The temperature extraction is accomplished by computer software. In the preliminary results documented here, the data transfer and interfacing between the computer programs are performed manually. In a fully developed system, a new-generation, high-speed, personal computer will be incorporated into the data acquisition with optimized software. Temperature output in a matter of seconds is no doubt possible.

SOME EXAMPLES

The multiwavelength pyrometry technique discussed in the "Pyrometry Methods" section was applied to analyze the real spectrum of two radiators. The problem is mathematically identical to the simulation described in the "Computer Experimentation" section.

There are two, commercial, Oriel, infrared sources that have data sheets providing the spectral irradiance from 1 to 20 μm (Oriel Corporation Catalog, Vol. II, Light Sources, Monochromators, Detector Systems, 1989.): the 22-W, 1550 K, 6575 ceramic element and the 100-W, 1000 K, 6363 infrared emitter. The data sheets provide enough information to determine temperatures of these sources (fig. 6). The data for these infrared sources were fitted to the single Planck curve (eq. (2)) and constant emissivity was assumed to obtain temperatures of 976 K (within 2.5 percent error) for the 6363 ceramic element and 1375 K for the 6575 infrared emitter (with an unacceptable error of almost 12 percent). Figure 7 shows the fitted curves and data for the two infrared sources.

The agreement for the 6363 source was very good; whereas, the agreement for the 6575 was certainly unacceptable. An examination of the graph in the data sheet revealed some structures in the spectrum between 3 and 6 μm ; the cause was suspected to be the variability in the 6575 emissivity with wavelength. Indeed, the manufacturer has provided, in the form of a broadband curve, the emissivity of the 6575 ceramic element as a function of wavelength (fig. 8). The emissivity data in that graph was fitted empirically to a Gaussian relation

$$\exp\left(-\frac{(\lambda - \lambda_0)^2}{2\sigma^2}\right) \quad (14)$$

producing a maximum at $\lambda_0 = 14 \mu\text{m}$ and $\sigma = 7.75 \mu\text{m}$.

This expression for the emissivity was then inserted explicitly into the Planck formula in equation (2), and the data was fitted accordingly. The temperature obtained is 1571 K, with an error of less than 1.5 percent from the nominal 1550 K. The fitted results, shown in figure 9, are an improvement from those shown in figure 7; nevertheless, in the region between 4 and 14 μm , the experimental data in figure 9 systematically exceed the calculated value obtained by curve fitting.

To explain this, we assume the presence of another radiator peaking at about 5 μm buried under the original curve. When the radiation from the second radiator is treated as if it were reflected from a surface described in the section, "Computer Experimentation," the mathematical expression describing the radiation from these two radiators can be immediately written as

$$L = L_{e1} + L_{e2} \quad (15)$$

or

$$L = e_1(\lambda) \frac{c_1}{\lambda^5} \frac{1}{\exp(c_2/\lambda T) - 1} + e_2(\lambda) \frac{c_3}{\lambda^5} \frac{1}{\exp(c_2/\lambda T_2) - 1} \quad (16)$$

where T and T_2 are the temperatures of the two radiators. The constants c_1 and c_3 now absorb the first radiation constant and the surface area of the emitting sources. Curve fitting produced $c_1 = 1602$, $T = 777$ K, $c_3 = 70$, and $T_2 = 1642$ K. The final fitting, shown in figure 10, is in excellent agreement with the data.

The decomposed spectrum, shown in figure 11, indicates that the infrared source 6575 actually contains two heating elements: one operating at a temperature of 1642 K and the other operating at 777 K. The emitting surface areas are approximately 20 to 1. The manufacturer confirmed that this infrared source is constructed with platinum wire wrappings buried in a cylinder of refractory material. During operation, there are effectively two heating elements exposed, and the ratio of their radii is about 10 to 1.

CONCLUSION

Computer curve fitting has been used in multiwavelength pyrometry to measure the temperature of a surface in the presence of reflected radiation. The technique was successfully applied to a computer-generated composite spectrum as well as real commercial sources. The ability of multiwavelength pyrometry to deconvolute the spectrum demonstrates the applicability of this technique to analysis of the complex spectrum of low-emissivity materials such as ceramics.

REFERENCE

1. Atkinson, W.; Cyr, M.A.; and Strange, R.R.: Development of Sensors for Ceramic Components in Advanced Propulsion Systems: Survey and Evaluation of Measurement Techniques for Temperature, Strain and Heat Flux for Ceramic Components in Advanced Propulsion Systems. (PWA-6113-12, Pratt and Whitney Aircraft; NASA Contract NAS3-25141), NASA CR-182111, 1988, pp. 33-34.
2. Hunter, G.B.; Allemand, C.D.; and Eagar, T.W.: Prototype Device for Multiwavelength Pyrometry. Opt. Eng., vol. 25, no. 11, Nov. 1986, pp. 1222-1231.
3. Gardner, J.L.; Jones, T.P.; and Davis, M.R.: Six Wavelength Radiation Pyrometer. High Temp.-High Press., vol. 13, no. 4, 1981, pp. 459-466.
4. Hunter, G.B.; Allemand, C.D.; and Eagar, T.W.: Multiwavelength Pyrometry: An Improved Method. Opt. Eng., vol. 24, no. 6, Nov.-Dec. 1985, pp. 1081-1085.
5. Ohno, J.: A New Method for Temperature Distribution Measurement Using Multispectral Radiance. Temperature: It's Measurement and Control in Science and Industry, Vol. 5, Pt. 1, J.F. Schooley, ed., American Institute of Physics, 1982, pp. 401-408.
6. Murray, T.P.: Polaradiometer - New Instrument for Temperature Measurement. Rev. Sci. Instrum., vol. 38, no. 6, June 1967, pp. 791-798.

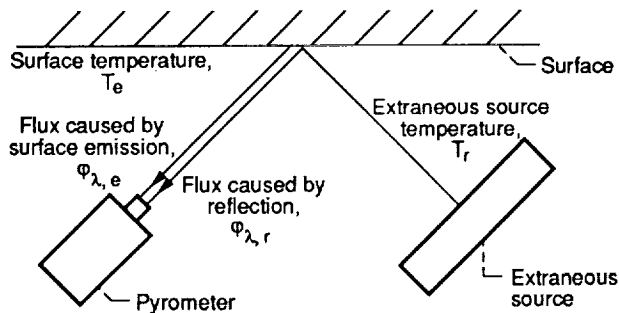


Figure 1. - Typical pyrometry geometry.

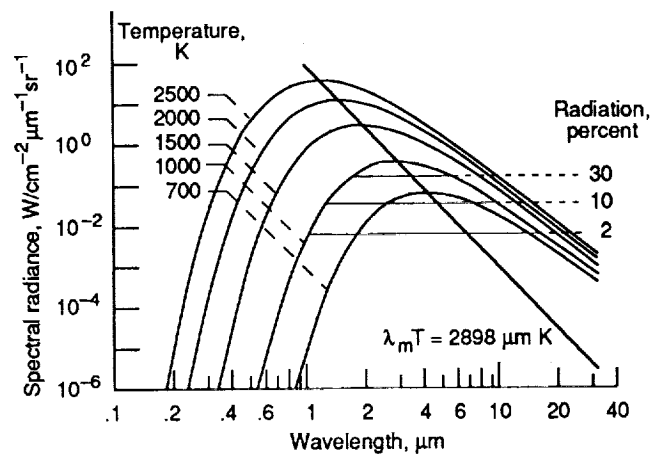


Figure 2. - Blackbody radiation curves. Wavelength bands that included radiations greater than 2, 10, and 30 percent of the 1000 K peak are shown.

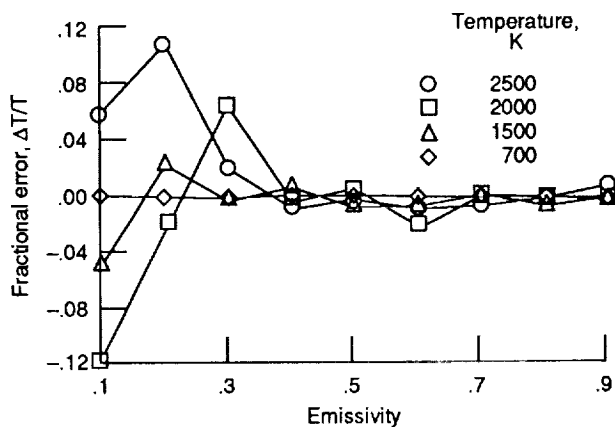


Figure 3. - Fractional error in surface temperature in presence of a blackbody as a function of emissivity. Surface temperature, 1000 K; channel spacing, 0.5 μm ; and spectral bandwidth, 0.3 to 20 μm .

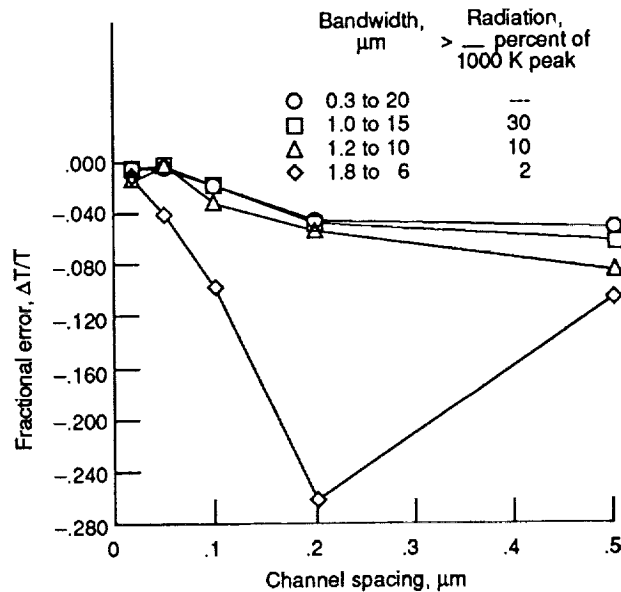


Figure 4. - Fractional error of surface temperature in presence of a blackbody as a function of channel spacing in wavelength region. Surface temperature, 1000 K; blackbody temperature, 1500 K; and emissivity of the surface, $e_e = 0.1$.

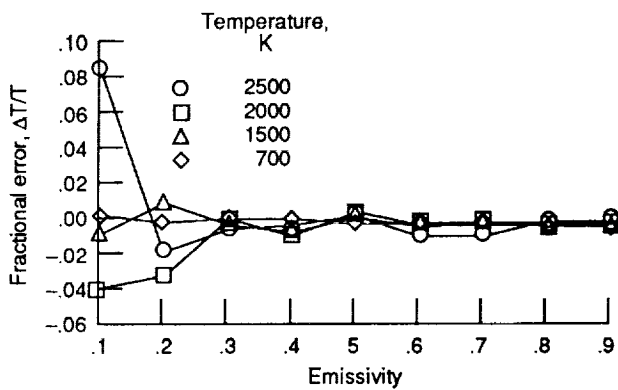


Figure 5. - Fractional error in surface temperature in presence of a blackbody as a function of emissivity. Surface temperature, 1000 K; spectrum channel spacing, 0.05 μm ; and spectral bandwidth, 0.3 to 20 μm .

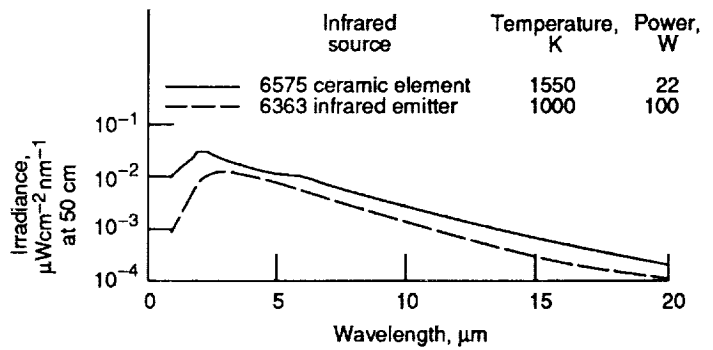


Figure 6. - Spectrum of two infrared sources. Typical spectral irradiance from bare element per 10-mm² area. (Oriel Corporation Catalog, Vol. II, Light Sources, Monochromators, Detector System, 1989.)

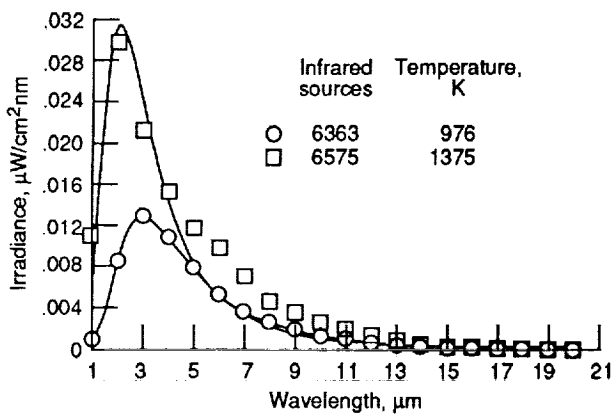


Figure 7. - Spectra of two infrared sources - fitted to Planck curves.

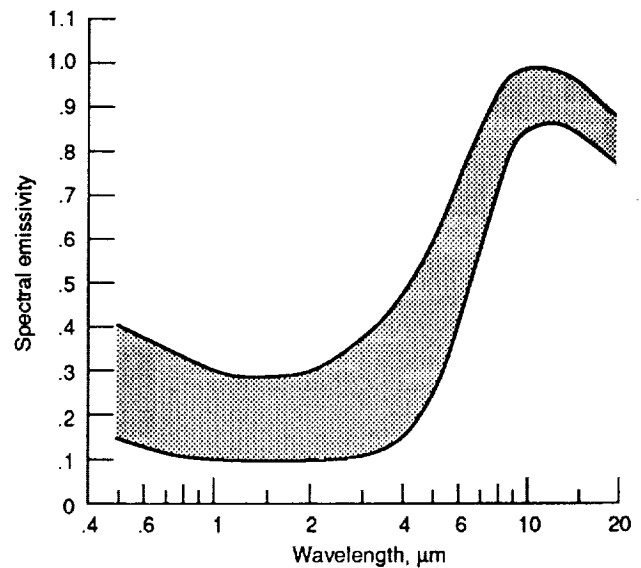


Figure 8. - Spectral emissivity of 6575 ceramic-element infrared heater. (Oriel Corporation Catalog, Vol. II, Light Sources, Monochromators, Detector System, 1989.)

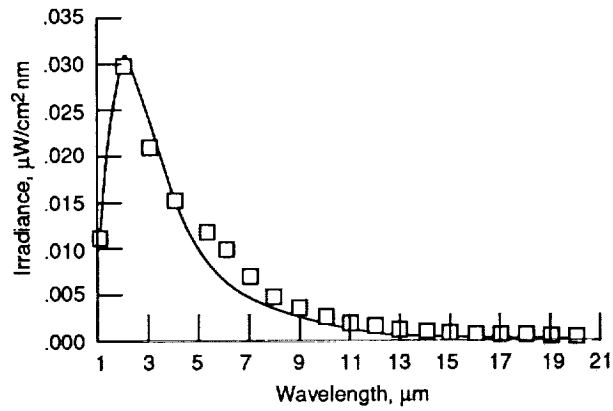


Figure 9. - Spectrum of 6575 ceramic-element lamp fitted to a Planck curve of temperature 1571 K and incorporating the spectral emissivity data.

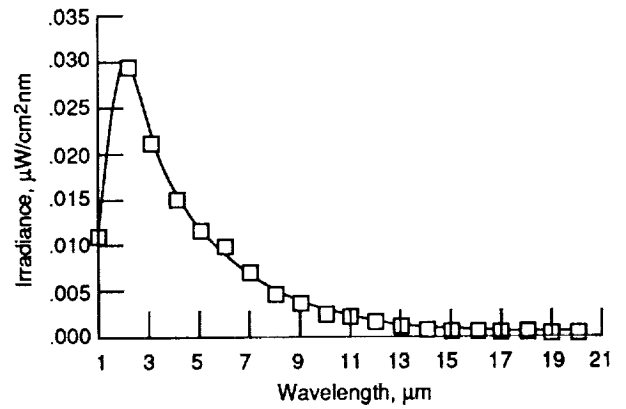


Figure 10. - Spectrum of 6575 ceramic-element lamp fitted to two Planck curves at temperatures of 1642 and 777 K and incorporating the spectral emissivity data.

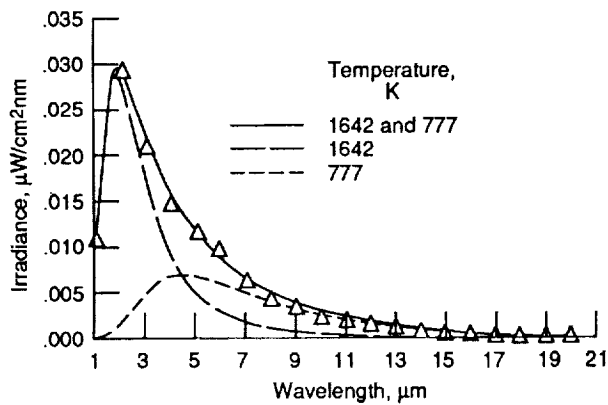


Figure 11. - Deconvolution of the spectrum of the 6575 ceramic-element infrared heater into the spectra of two Planck functions and incorporating experimental data.

Report Documentation Page

1. Report No. NASA TM-102578		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Multiwavelength Pyrometry to Correct for Reflected Radiation				5. Report Date June 1990	
				6. Performing Organization Code	
7. Author(s) Daniel L.P. Ng				8. Performing Organization Report No. E-5409	
				10. Work Unit No. 510-01-0A	
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191				11. Contract or Grant No.	
				13. Type of Report and Period Covered Technical Memorandum	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546-0001				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract Computer curve fitting is used in multiwavelength pyrometry to measure the temperature of a surface in the presence of reflected radiation by decomposing its radiation spectrum. Computer-simulated spectra (at a surface temperature of 1000 K; in the wavelength region 0.3 to 20 μm ; with a reflected radiation-source temperature of 700 to 2500 K; and reflector emissivity from 0.1 to 0.9) were generated and decomposed. This method of pyrometry determined the surface temperatures under these conditions to within 5 percent. The practicability of the method was further demonstrated by the successful analysis of a related problem—decomposition of the real spectrum of an infrared source containing two emitters to determine their temperatures.					
17. Key Words (Suggested by Author(s)) Multiwavelength pyrometry Computer curve fitting Surface temperature measurement				18. Distribution Statement Unclassified—Unlimited Subject Category 35	
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of pages 12	
				22. Price* A03	